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Method for improving the uniformity of an electrophoretic display

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Method for improving the uniformity of an electrophoretic display

The invention relates to a method for improving the uniformity of an electrophoretic display with a plurality of display pixels, said display pixels being adapted to represent one or more grey levels by receiving driving signals.

US 2002/0196526 discloses an electrophoretic device, wherein a driving voltage is applied over a first and a second electrode to allow electrophoretic particles to localize at either the first or the second electrode by electrophoresis.

In more recent electrophoretic displays multiple grey levels are obtained via e.g. time-weighted drive periods or division of the display pixels into surfaces with different areas.

A problem associated with the known electrophoretic displays is non-uniformity, which is especially observed when changing from one grey level to another. In particular, the displays have been observed to suffer from a form of image retention, whereby the actual grey level of a pixel in a new image may depend upon the grey level of that pixel in a previous image. In such cases, a previous image may be partially visible in a new image. These problems are believed to be caused by strong memory effects (bi-stability) and dwell time effects. The dwell time of a particular display pixels is generally defined as the period in which no voltage was applied to that pixel.

It is an object of the invention to provide a method for improving the uniformity of an electrophoretic display and in particular to reduce the form of image retention described above.

This object is achieved by the method comprising the steps of:

- displaying a first calibration image containing said grey levels in a first arrangement on said electrophoretic display;
- switching from said first calibration image to at least a second calibration image containing said grey levels in a second arrangement on said electrophoretic display;

- determining non-uniformity artefacts by comparing said second calibration image with a required image;
- adjusting said driving signals such that said required image and said second calibration image match.

By switching from the first calibration image to the second calibration image grey level transitions can be determined on the electrophoretic display that do not comply with the expected switch in grey level for a particular grey level as defined by the required image. After having determined the deviations, the artefacts are repaired by adjusting the driving signals for the display pixels, such that the required image is achieved in terms of brightness. As a result the display appearance is improved and, more specifically, the effects of image retention are reduced. This calibration method preferably constitutes a step in the manufacturing of an electrophoretic display.

In a preferred embodiment of the invention said first arrangement and said second arrangement are such that in said switching all possible grey level transitions are involved. In this situation it is possible to determine all non-uniformity artefacts at once.

In a preferred embodiment of the invention said first calibration image and said second calibration image comprise one or more blocks of individual display pixels or groups of display pixels respectively forming said first and second arrangement. The blocks may substantially entirely cover said electrophoretic display. By having several repeats of the calibration patterns of blocks distributed over the electrophoretic display lateral, i.e. variations across the display, non-uniformity artefacts can be determined. As a result, the display uniformity is also improved. It may occur that the driving signals need to be adjusted differently for different locations on the display.

In a preferred embodiment the second calibration image is recorded by a CCD-camera to determine said non-uniformity artefacts. The CCD-camera may record the second calibration image and therefore determine the deviations from the required image for the entire display at once.

In a preferred embodiment of the invention the method further comprises the step of modifying a look-up table for said electrophoretic display in accordance with said adjusted driving signals. Before calibration a default look-up table may be present used in driving the display pixels. It may appear that this default look-up table needs to be modified after the determination of the non-uniformity artefacts for adjusting the driving signals. Preferably these driving signals relate to driving voltages, reset voltages and/or pre-pulse voltages and said adjustment involves modifying the magnitude and/or duration of said

voltages and/or changing or introducing periods between the driving voltages and/or adding additional voltage pulses. This modification allows restoration of the grey levels in accordance with the required image.

In an embodiment of the invention the method further comprises the steps of:

- recording said first calibration image and comparing said first calibration image with a further required image;
- adjusting said driving signals such that said first calibration image and said further calibration image match.

By also recording the first calibration image, e.g. by the CCD-camera, information on the initial or first arrangement can be obtained. This first arrangement of the first calibration image may need to be adjusted in order to arrive at a suitable block of grey scale levels to obtain a transition for all possible grey levels on switching to the second calibration image, as described above.

In an embodiment of the invention further calibration images may be displayed on the electrophoretic display. This may prove to be advantageous in improving the uniformity across the electrophoretic display. Moreover such further calibration images may be used in situations wherein the previous history of the display pixels is important, i.e. not the previous image, but two or more images ago. In this case a third calibration image may be used wherein each block is split into smaller blocks with different grey levels.

In an embodiment of the invention the above method is repeated one or more times after adjusting said driving signals. By such a repetition of the method it may be verified whether the adjusted driving signals actually improved the uniformity of the electrophoretic display.

The invention also relates to a device comprising an electrophoretic display being manufactured by the method as described above.

US 6,473,065 discloses methods for improving display uniformity of organic light emitting displays by calibrating individual pixels. In this publication only lateral non-uniformity variations are adjusted for, whereas according to the invention primarily grey level transitions are adjusted. Moreover as the prior art methods are aimed at organic displays instead of electrophoretic displays, a single measurement is sufficient for improving the uniformity, since no substantial memory effects for uniformity occur for organic display pixels. In contrast, for electrophoretic displays strong memory effects arise resulting in the need for generating at least two calibration images.

The invention will be further illustrated with reference to the attached drawings, which show preferred embodiments of the invention. It will be understood that the device and method according to the invention are not in any way restricted to this specific and preferred embodiment.

Fig. 1 shows a schematic illustration of an electrophoretic display;

Fig. 2 shows a cross-section view along II-II in Fig. 1;

Fig. 3 shows a schematic illustration of a set-up for performing the method according to an embodiment of the invention;

Fig. 4 shows examples of calibration images and a required image according to an embodiment of the invention;

Fig. 5 shows examples of adjusted driving signals as a result of the method according to an embodiment of the invention.

Figs. 1 and 2 show an embodiment of an electrophoretic display 1 of a device D having a first substrate 8, a second opposed substrate 9 and a plurality of display pixels 2. Preferably, the display pixels 2 are arranged along substantially straight lines in a two-dimensional structure. Other alternatives include e.g. a honeycomb structure. An electrophoretic medium 5, having charged particles 6, is present between the substrates 8 and 9. In Fig. 2 the first substrate 8 has for each display pixel 2 a first electrode 3, and the second substrate 9 has for each display pixel 2 a second electrode 4. The electrodes 3, 4 are adapted to receive a driving signal from drive means 10. The charged particles 6 are able to occupy extreme positions near the electrodes 3,4 and intermediate positions in between the electrodes 3,4. In this way grey levels can be obtained. Each display pixel 2 has an appearance determined by the position of the charged particles 6 between the electrodes 3,4 for displaying the picture or image. Electrophoretic media 5 are known per se from e.g. US 5,961,804, US 6,120,839 and US 6,130,774 and can e.g. be obtained from E Ink Corporation. As an example, the electrophoretic medium 5 comprises negatively charged black particles 6 in a white fluid. When the charged particles 6 are in a first extreme position, i.e. near the first electrode 3, as a result of the potential difference being e.g. 15 Volts, the appearance of the picture element 2 is e.g. white. Here it is considered that the picture element 2 is observed from the side of the second substrate 9. When the charged particles 6 are in a second extreme

position, i.e. near the second electrode 4, as a result of the potential difference being of opposite polarity, i.e. –15 Volts, the appearance of the picture element 2 is black. When the charged particles 6 are in one of the intermediate positions, i.e. in between the electrodes 3,4, the picture element 2 has one of the intermediate appearances, e.g. light grey and dark grey, which are grey levels between white and black. The drive means 10 is arranged for driving each display pixel 2 by supplying appropriate voltages to the electrodes 3, 4 using a look-up table (LUT) 11. Appropriate driving signals are e.g. described in the non-prepublished patent application EP 03100133 of the applicant. In an active matrix embodiment, the pixel may further comprise switching electronics comprising for example thin film transistors (TFTs), diodes or MIM devices.

Fig. 3 shows a schematic illustration of a set-up 20 for performing the method according to an embodiment of the invention. The set-up 20 comprises the electrophoretic display 1 shown in Figs. 1 and 2, drive means 10 and a CCD-camera 21.

The operation of the set-up 20 will be described with reference to Fig. 4, showing a first calibration image 22, a required image 23 and a second calibration image 24. The images 22, 23 and 24 are divided in arrangements of blocks 25 of display pixels 2 covering the entire display 1. Alternatively a multiplicity of such arrangements may be distributed over the electrophoretic display 1 to visualize lateral non-uniformity effects.

The first arrangement for the first calibration image 22 is such that it comprises all possible, in this case four, grey levels, indicated by the white (W), light grey (LG), dark grey (DG) and black (B) blocks 25. The second arrangement of the second calibration image 24 is chosen such that in the transition from the first calibration image 22 to the second calibration image 24 all grey level transitions are involved. That is, for compliance to the required image 23, the upper four blocks 25 should all switch to W, the subsequent four blocks 25 to LG, the next four blocks 25 to DG and the bottom four blocks 25 to B. Further calibration images may be displayed if need be. In this manner, memory effects persisting over more than one image update may also be corrected for. It is further noted that different arrangements for the calibration images are possible, depending upon details of the display 1 and the resolution of the optical measurement system 21.

In operation the fabricated electrophoretic display is placed under an optical imaging system, such as the CCD-camera 21. Then the display 1 may be initialized to a well-defined state by providing particular driving signals from the drive means 10. Next the first calibration image 22 is generated on the display 1 and the brightness of the grey levels for the display pixels 2 is recorded by the CCD-camera 21. If the brightness of the initial grey levels

is not correct the driving signals are adjusted in accordance with the results of the measurements for the CCD-camera 21. The adjustments may be stored in the LUT 11. The display 1 may be initialized once more and the first calibration image 22 may be re-displayed until the correct brightness levels are obtained as shown in Fig. 4.

Subsequently a second calibration image 24 is displayed by switching from the first calibration image 22. In this way non-uniformity artefacts 26 are determined arising from image retention and other effects. The determination of the non-uniformity artefacts 26 is performed by a comparison with the required image 23, being the ideal image when all grey level transitions were successfully obtained. Here the artefacts are twofold, the transition B to W yielded a not entirely white block 25, whereas the transition W to DG yielded a too dark block 25.

The driving signals are adjusted for the display pixels 2 of the blocks 25 showing the non-uniformity artefacts 26. This adjustment may be achieved by modifying the LUT 11 of the drive means 10.

If necessary the display 1 may be re-initialized and the method may be repeated with new driving signals.

Fig. 5 shows an example of suitable driving signals 30 for the display pixels 2 of the electrophoretic display 1. These driving signal include pre-pulse voltages 31, driving voltages 33 and optionally reset voltages 32. The pre-pulse voltages 31 may release the particles 6 from their extreme positions near the electrodes 3, 4 without enabling the particles to substantially transfer to the other electrode 3, 4. The reset voltages 32 may reduce the dependence of a display pixel 2 on the previous appearance or representation because the particles 6 substantially occupy an extreme position. It is noted that the time during which the reset voltage 32 is applied may be extended as described in the non-pre-published patent application EP 03100133 of the applicant. The driving voltage 33 transfers the particles 6 to the position corresponding to the image information for the display pixel 2. Adjustment of the driving signals 30 to improve uniformity of the display 1 may include adjusting the magnitude and duration of the pre-pulse voltages 31 and/or the reset voltages 32 and/or the driving voltages 33, but may also involve changing or introducing periods between the driving voltages 33 in the dwell time and/or introducing additional voltage pulses. This adjustment is preferably performed by modifying the LUT 11.

CLAIMS:

1. Method for improving the uniformity of an electrophoretic display (1) with a plurality of display pixels (2), said display pixels being adapted to represent one or more grey levels by receiving driving signals (30), comprising the steps of:

- displaying a first calibration image (22) containing said grey levels in a first arrangement on said electrophoretic display;
- switching from said first calibration image (22) to at least a second calibration image (24) containing said grey levels in a second arrangement on said electrophoretic display;
- determining non-uniformity artefacts (26) by comparing said second calibration image (24) with a required image (23);
- adjusting said driving signals (30) such that said required image (23) and said second calibration image (24) match.

2. Method according to claim 1, wherein said first arrangement and said second arrangement are such that in said switching all possible grey level transitions are involved.

3. Method according to claim 1, wherein said first calibration image and said second calibration image comprise one or more blocks (25) of individual display pixels or groups of display pixels respectively forming said first and second arrangement.

4. Method according to claim 3, wherein said blocks substantially entirely cover said electrophoretic display.

5. Method according to claim 1, further comprising the step of recording said second calibration image by a CCD-camera (21) to determine said non-uniformity artefacts.

6. Method according to claim 1, wherein said method further comprises the step of modifying a look-up table (11) for said electrophoretic display in accordance with said adjusted driving signals.

7. Method according to claim 1, wherein said driving signals comprise driving voltages (33), and/or reset voltages (32) and/or pre-pulse voltages (31) and said adjustment involves modifying the magnitude and/or duration of said voltages and/or changing or introducing periods between the driving voltages and/or introducing additional voltage pulses.

8. Method according to claim 1, wherein said method further comprises the steps of:

- recording said first calibration image and comparing said first calibration image with a further required image;
- adjusting said driving signals such that said first calibration image and said further calibration image match.

9. Method according to claim 1, wherein said method further comprises the step of displaying further calibration images on said electrophoretic display.

10. Method according to claim 1, wherein said method is repeated one or more times after adjusting said driving signals.

11. Device (D) comprising an electrophoretic display (1) being manufactured according to the method of claim 1.

ABSTRACT:

The invention relates to a method for improving the uniformity of an electrophoretic display (1) with a plurality of display pixels (2), said display pixels being adapted to represent one or more grey levels by receiving driving signals. The method comprises the steps of displaying a first calibration image (22) containing said grey levels in a first arrangement on said electrophoretic display; switching from said first calibration image (22) to at least a second calibration image (24) containing said grey levels in a second arrangement on said electrophoretic display; determining non-uniformity artefacts (26) by comparing said second calibration image (22) with a required image (23), and adjusting said driving signals such that said required image (23) and said second calibration image (24) match. By this method the uniformity of the electrophoretic display (1) is improved.

Fig. 4

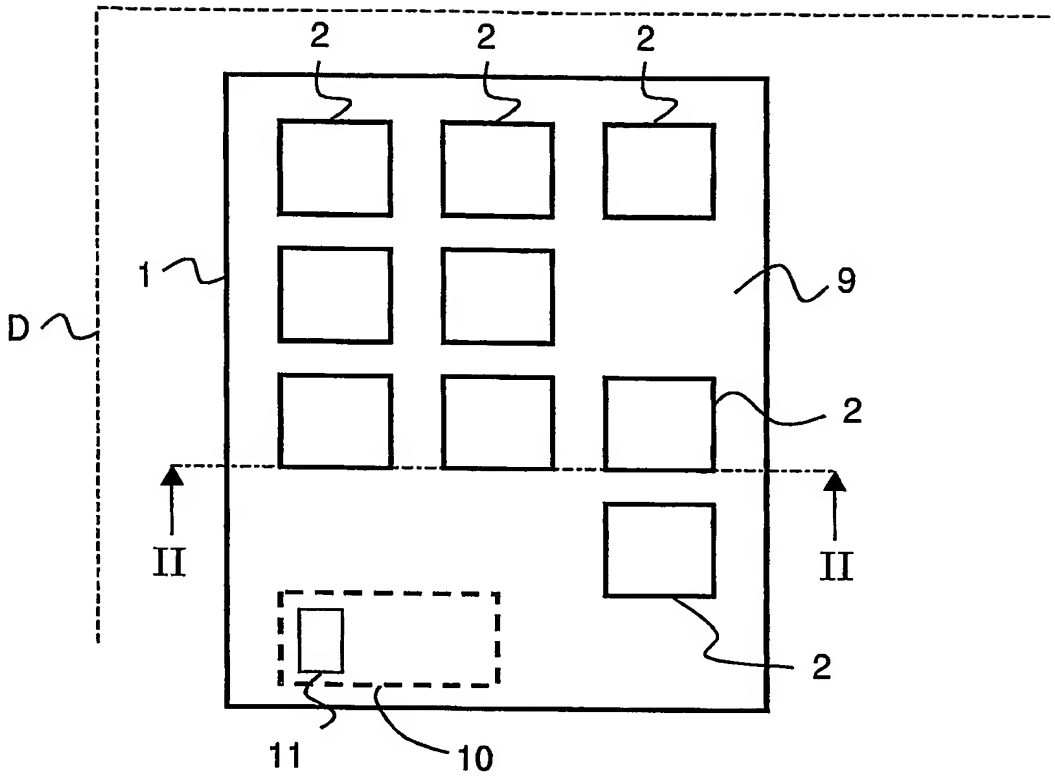

FIG.1

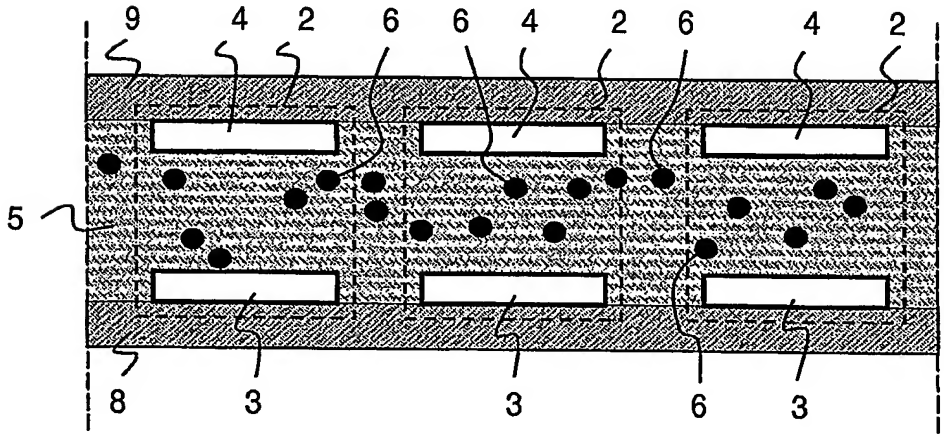

FIG.2

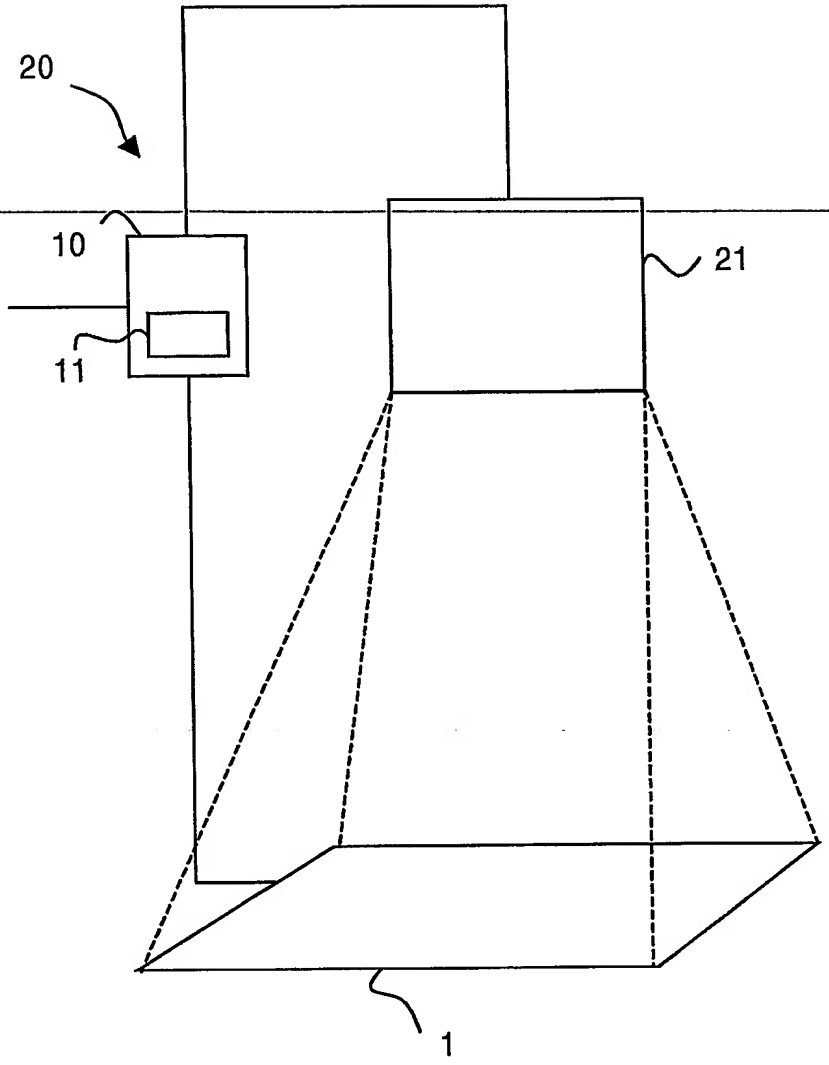

FIG.3

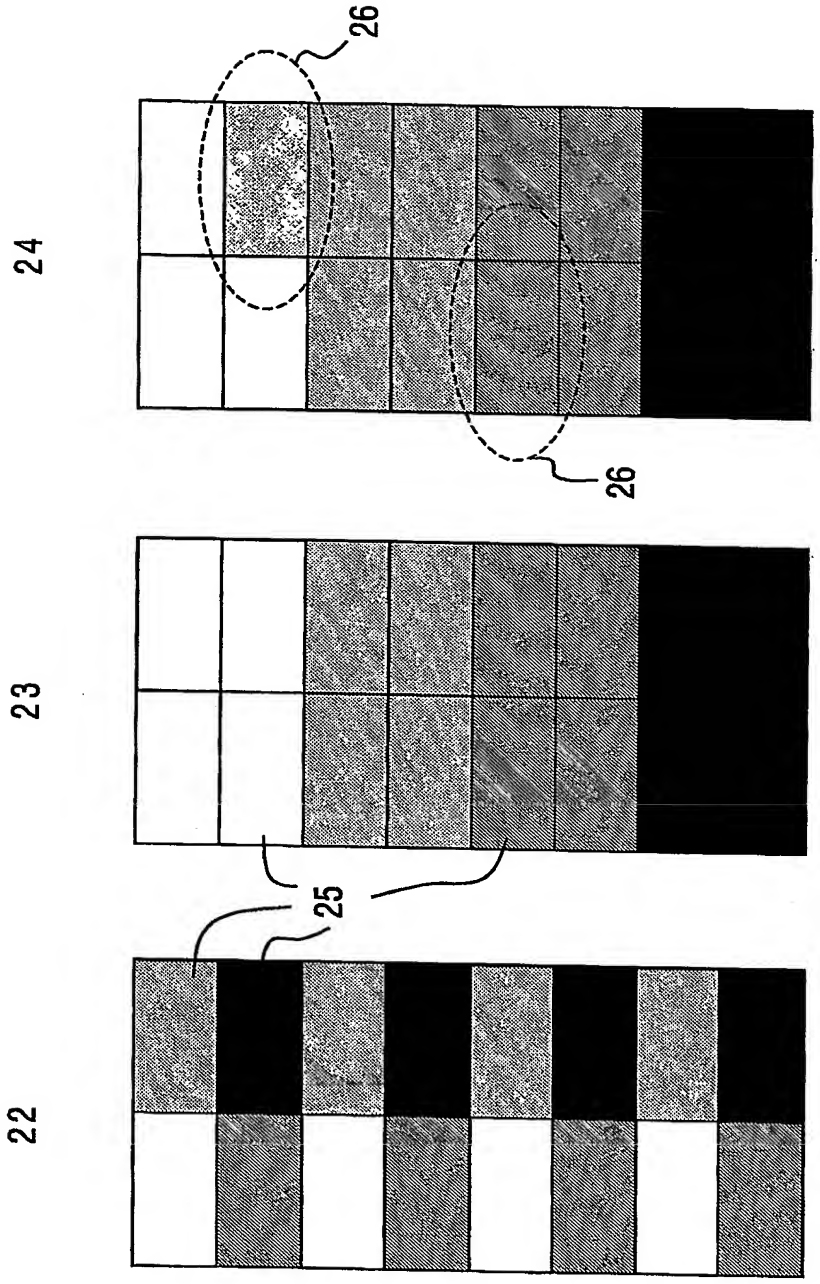

FIG.4

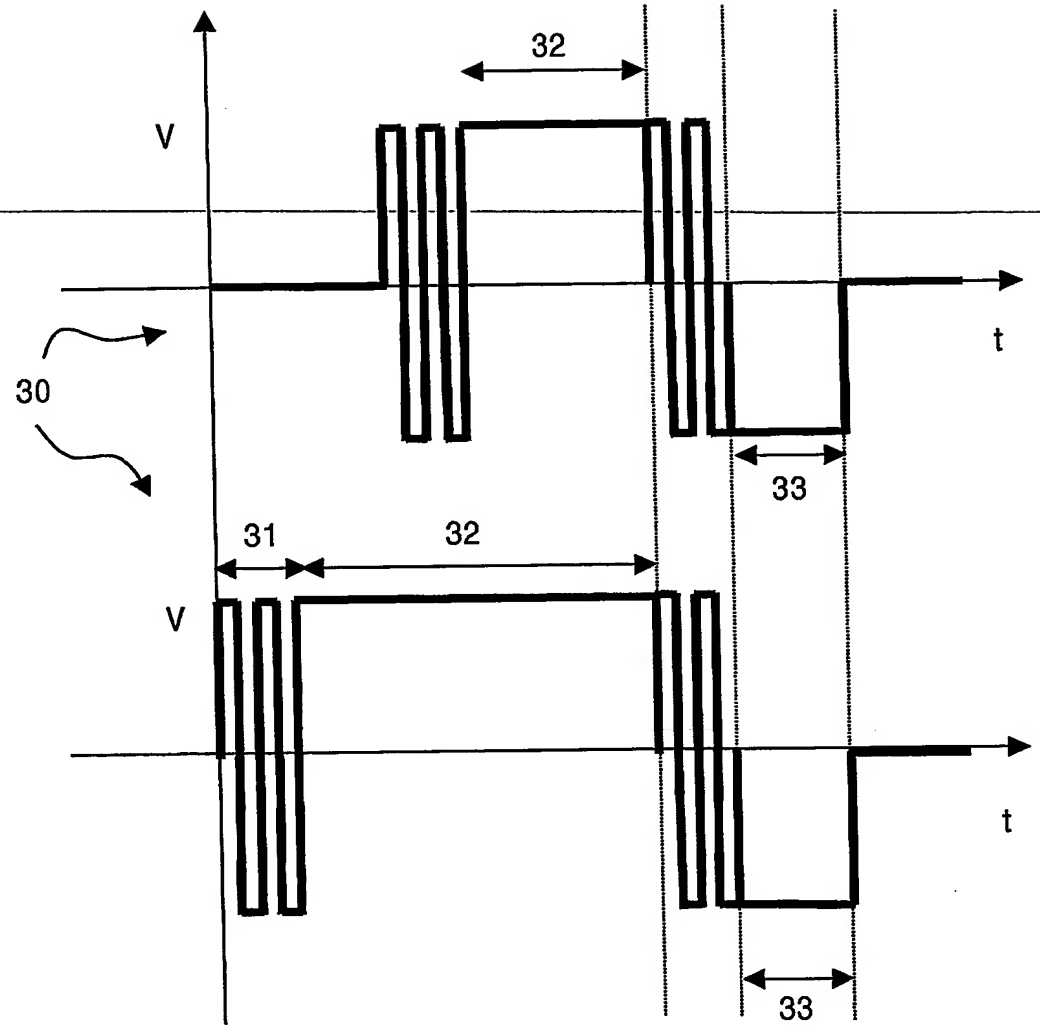

FIG.5

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